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DESIGN OF A SYSTEM FOR CUTTING SHAPED CHARGE JETS FOR PENETRATION EXPERIMENTS

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JUNE 1987

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An experimental system to selectively cut a copper jet from a 34.9 mm diameter shaped-charge is described. Parameters for the uncut jet are also given. The system was designed to be used in the study of jet penetration in glass and ceramic targets.

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1. INTRODUCTION

A shaped charge is a jet forming device consisting of an explosive charge containing a cavity. The cavity is lined with a thin metallic layer called a liner.[1] Circular cylindrical charges with either conical or hemispherical lined cavities are extensively used as penetrators in many anti-armor applications. There are also charges with linear cavities having triangular or semicircular cross section, so called "cutting charges". These charges, as the name implies, are used to cut plates or similar configurations usually made of metal.

When a regular cone-liner shaped charge is detonated, the high pressure detonation products collapse the metal liner upon itself and form a high velocity, cylindrical, metallic jet. The jet produced can penetrate high strength materials. During the collapse process different parts of the jet experience different collapse velocities producing a velocity gradient in the jet. The tip of the jet travels faster than each succeeding portion. This gradient causes the jet to stretch and eventually fracture into a series of discrete particles. In the case of the cutting charge, the jet formed has lateral extent, which produces a slit or cut in the target instead of the circular hole produced by a conical liner.

The subject of this report is experiments in which a 150 KV flash X-ray system was used to determine the parameters of the jet formed by a regular conical liner shaped charge and to design a cutting charge. The cutting charge was used to selectively cut the jet produced by the conical shaped charge so that different velocities or lengths could be directed to the targets. This experimental system was designed to be used in the study of jet penetration in glass and ceramic target materials.

2. EXPERIMENTAL PROCEDURE

A two channel 150 KV flash X-ray system* was used to observe the jet following the standard shadowgraph technique in which the jet interupts a short duration X-ray beam and produces a shadow of itself on film mounted behind. Two exposures at different times on the same film allow the determination of the velocity and position of each jet particle. The position of the film with respect to the base of the charge and the magnification of the image caused by the beam divergence were determined by fiducial marks exposed on the film prior to the experiment. This was done by placing a lead sheet, 3.12 mm thick with a pattern of 3.3 mm diameter drilled holes, in the proposed jet path. The X-ray tubes were then fired with the film in place. This produced a double pattern of circular images on the film with known separation distances in the plane of the jet. The lead sheet was subsequently removed when the experiments were performed.

[1]Birkhoff, G., MacDougal, D. P., Pugh, E. M., and Taylor, G. I., "Explosives with Lined Cavities," Journal of Applied Physics, Vol 19, No. 6, p. 563, June 1948.

*Hewlett-Packard, McMinville, OR

The X-ray film and suitable intensifier screens* were placed in a felt-lined steel cassette with a 12.7 mm thick polyethylene cover plate on the side exposed to the X-ray beams. This protected the film from the explosive blast and the disturbances caused by the propagating jet. The times between X-ray pulses were measured with both the trigger signals and the signals from the X-ray tube current monitors and were displayed on digital oscilloscopes**. The detonators were fired using a high voltage (4KV) pulse power supply which permitted sub-microsecond timing of the explosive event.

3. EXPERIMENTS WITH THE CONE-LINER SHAPED CHARGE

The unconfined shaped charge used in this study is shown in Figure 1. The copper liner is 0.91 mm thick and has a rounded apex. The figure gives other essential dimensions of the charge and the parts of the explosive train. Various jet parameters were measured in 6 experiments examining three complete jets and three jets truncated with the cutting charge.

The velocities and the distance from the base of the charge were measured for all particles which appeared on both dynamic exposures of the films. A linear least squares fit was made of these velocity-distance data for each jet at the two exposure times. The intersections of these lines with the distance axis gave the virtual origin of the jet. For the 6 experiments, 12 values were obtained. The average value for the distance of the origin from the base of the liner was -45.5 ± 0.8 mm. Figure 2 shows a plot of the data from test No. 14. The average jet tip velocity was 7.84 ± 0.04 km/s. The breakup time of the jet was measured from particle lengths[2] to be 40.1 microseconds after detonator firing or 20.7 microseconds from the time the jet tip reached the base of the charge. This corresponds to 4.64 charge diameters. The jet diameter was approxiamtely 1.0 mm with an average particle length of 2.6 mm.

4. DESIGNING A CUTTING CHARGE

The cutting charge was designed with two purposes in mind. The first purpose was to produce a leading particle of sufficient areal extent and velocity to quickly cut a passing jet fired perpendicular to it. The second was to deflect the remaining jet and slug so that they would miss a hole in a plate of armor steel through which the first part of the jet had passed. It was supposed that a charge of sufficient size to accomplish the first purpose would also achieve the second.

Preliminary experiments were performed using triangular liners made from 1.35 mm thick copper sheet bent to form a trough with a 45° apex angle. A rectangular box made of acrylic plastic was placed around the

*Kronex NDT 91 X-ray Film, 3M TriMax12 Screens
**Nicolet Oscilloscope Div., Madison, WI. (Model 2000, 204A Plug-in)

[2] Chou, P. C., and Carleone, J., "Shaped Charge Jet Break Up Studies Using Radiographic Measurement and Surface Instability Calculations," ARBRL CR-337, 1977.

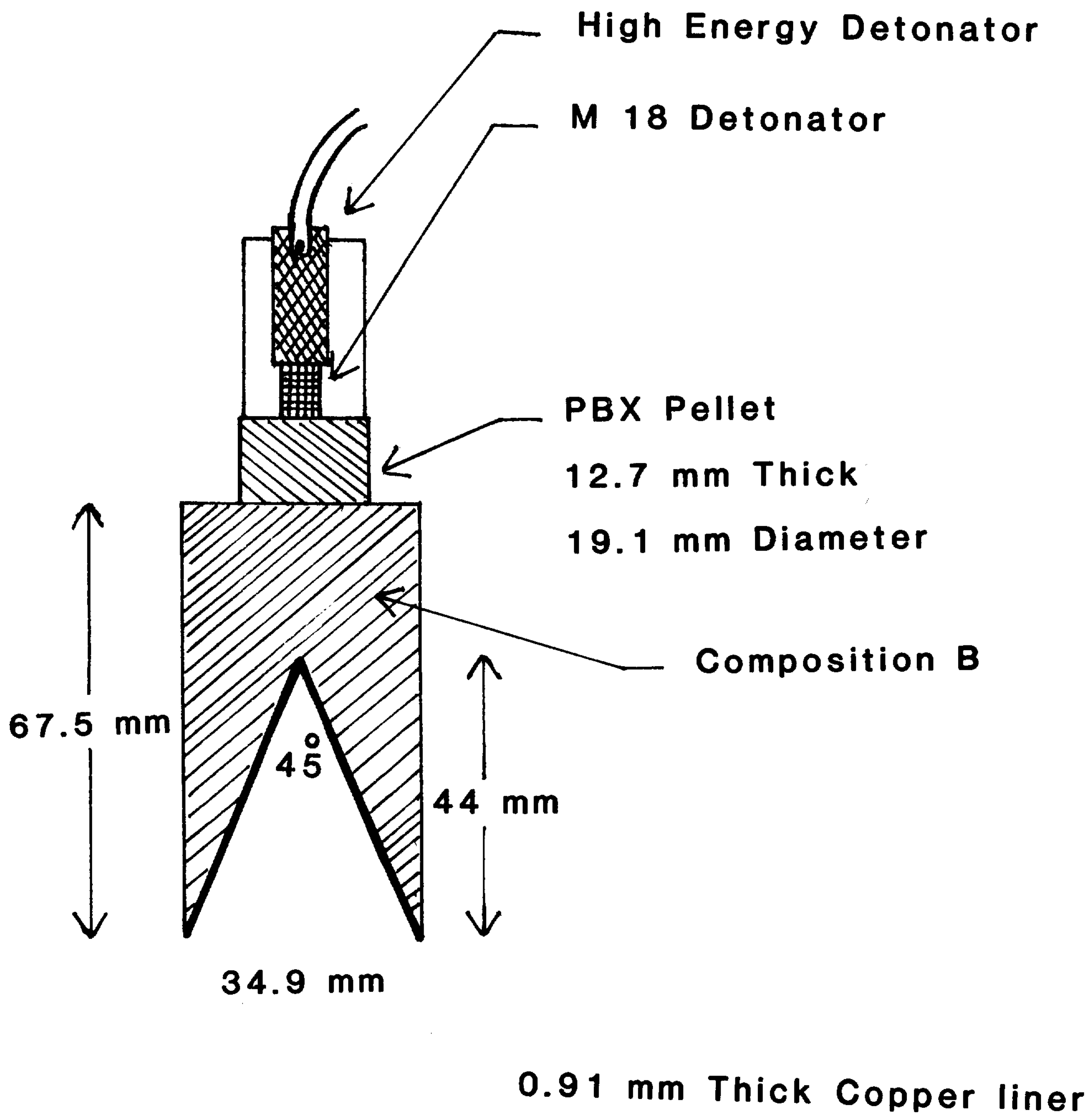

Figure 1. Conical-Liner Shaped Charge

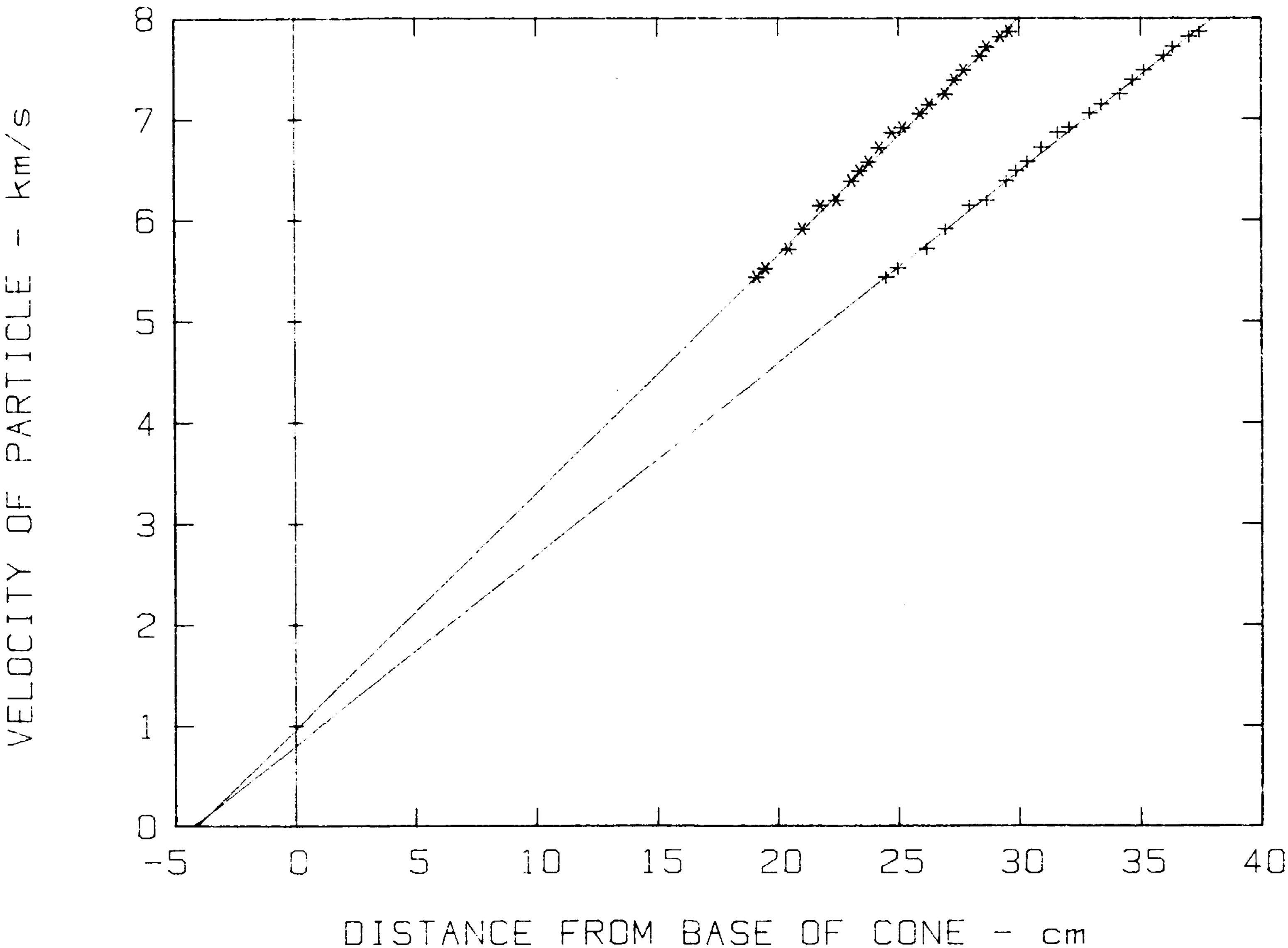

Figure 2. Velocity vs Distance for Jet Particles, from Test 14

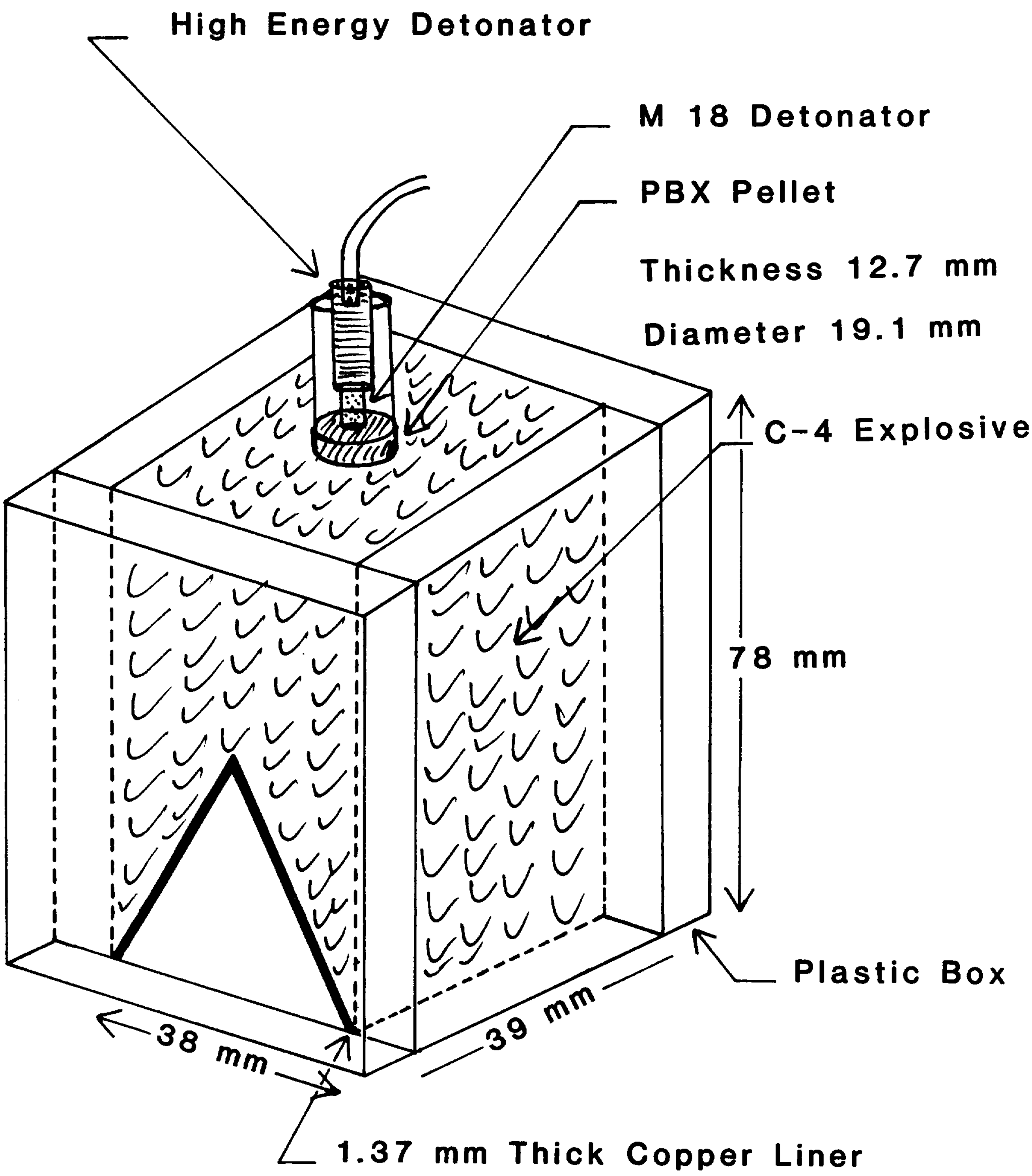

Figure 3. Linear Charge With Triangular Liner

liner and filled with C-4 plastic explosive. Figure 3 gives dimensions and details of the charge and the explosive train. This charge did not produce a leading particle of sufficient size. One experiment was performed in which the liner length was increased from 39 mm to 75 mm. The explosive was detonated along a center line above the liner apex with a Deta-sheet* line wave generator instead of at the center of the charge (see Figure 4). This design did not form a good leading particle either, although the velocity of the particle that did form was higher (5.73 km/s).

A new charge was then designed using a liner with a semi-circular cross section. The liner was made by cutting regular commercial copper tubing into two halves. The tubing had a wall thickness of 1.57 mm, an outside diameter of 34.9 mm, and a length of 50.8 mm. The charge was a cube of C-4 plastic explosive 50.8 mm on a side with a cavity for the liner in the middle of one face. An acrylic plastic box surrounded the explosive and liner. The charge was detonated along the cylindrical axis of the liner in the same manner as the charge of Figure 4. Figure 5 shows the charge and gives dimensions.

This design yielded a usable leading particle which traveled at a comparably reduced yet acceptable velocity of 3.03 km/s. Experiments were then performed to cut the regular conical liner jets. These experiments are described in Section 5. In order to make construction of the cutting charges easier, reusable aluminum molds were made and Composition B explosive replaced C-4 in a charge of the same dimensions. This change gave a slightly higher leading particle velocity of 3.16 km/s. Table I gives details of the four different cutting charge designs.

5. EXPERIMENTAL SYSTEM FOR CUTTING JETS

The experimental system that was finally used is shown in Figure 6. The conical shaped charge is supported by a piece of aluminum alloy tubing with a 12.7 mm wide slot cut into its side so as not to disturb the cutting jet. The initial portion of the penetrating jet passes through a 9.5 mm diameter hole in a 25.4 mm thick plate of armor steel. The rest of the jet and the slug are deflected by the cutting charge, miss the hole, and are stopped by the steel plate. Different lengths of jet can be cut by changing the position of the cutting charge with respect to the aluminum tube support or by changing the timing of the detonation of the charges. The spacing and timing must be controlled so that the cutting charge does not interfere with the formation of the penetrating jet. Figure 7 is an X-ray of a jet cut when it was approximately 98 mm long, just before breakup.

In order to select different velocities or sections of the jet, the jet was made to penetrate mild steel plates and wipe off its leading part. Figures 8 and 9 show X-rays of a jet cut off at the same length but in the case of Figure 9 also penetrating a 6.36 mm mild steel plate placed at a 60° angle to the jet path. As can be seen, the first particles of the jet are wiped off and the tail is cleaned up. Table II gives velocities of the individual jet particles in the two X-rays.

*E. I. Dupont de Nemours and Co., Inc., Explosives Product Division, Wilmington, DE 19898.

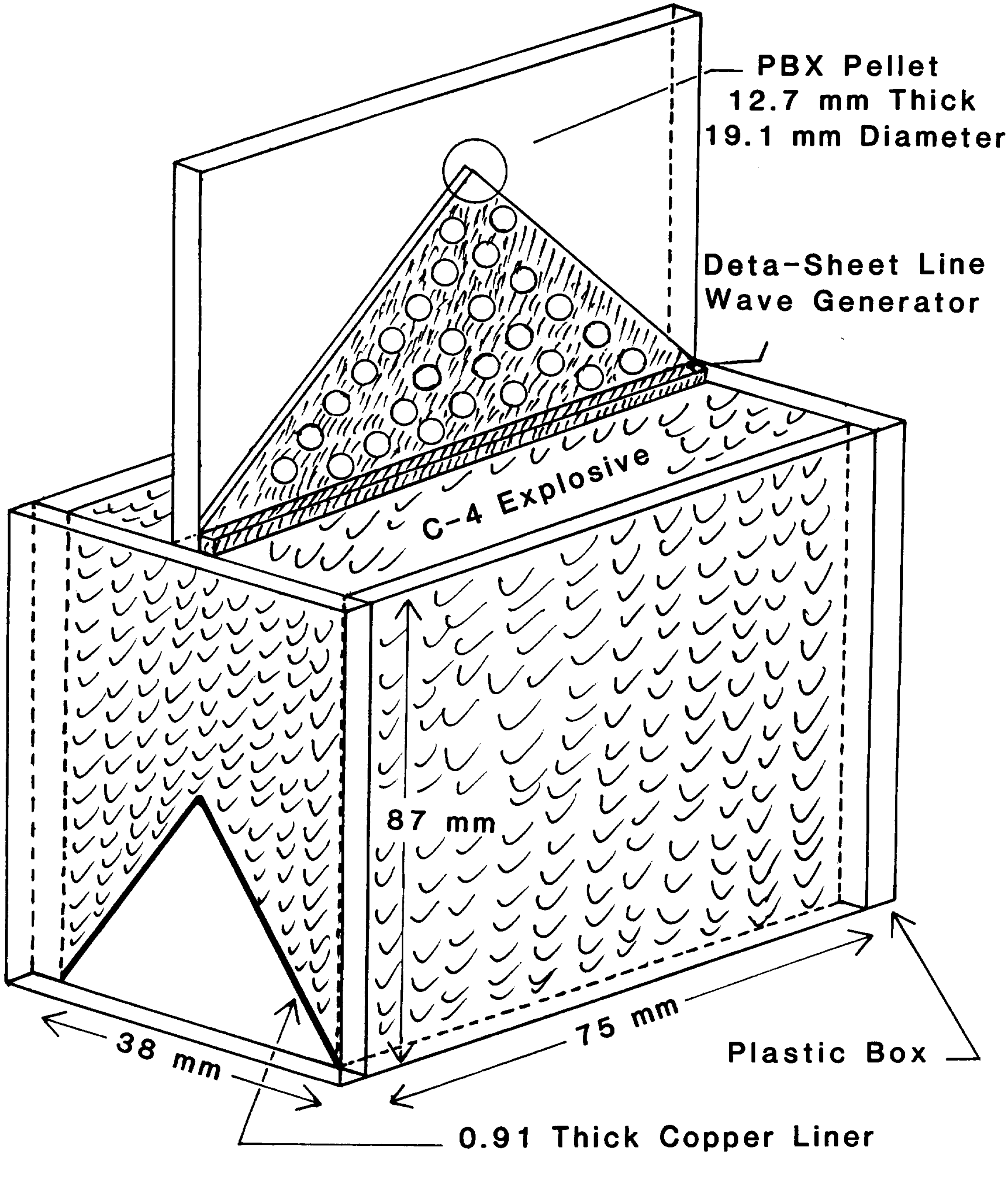

Figure 4. Linear Charge With Line Wave Generator

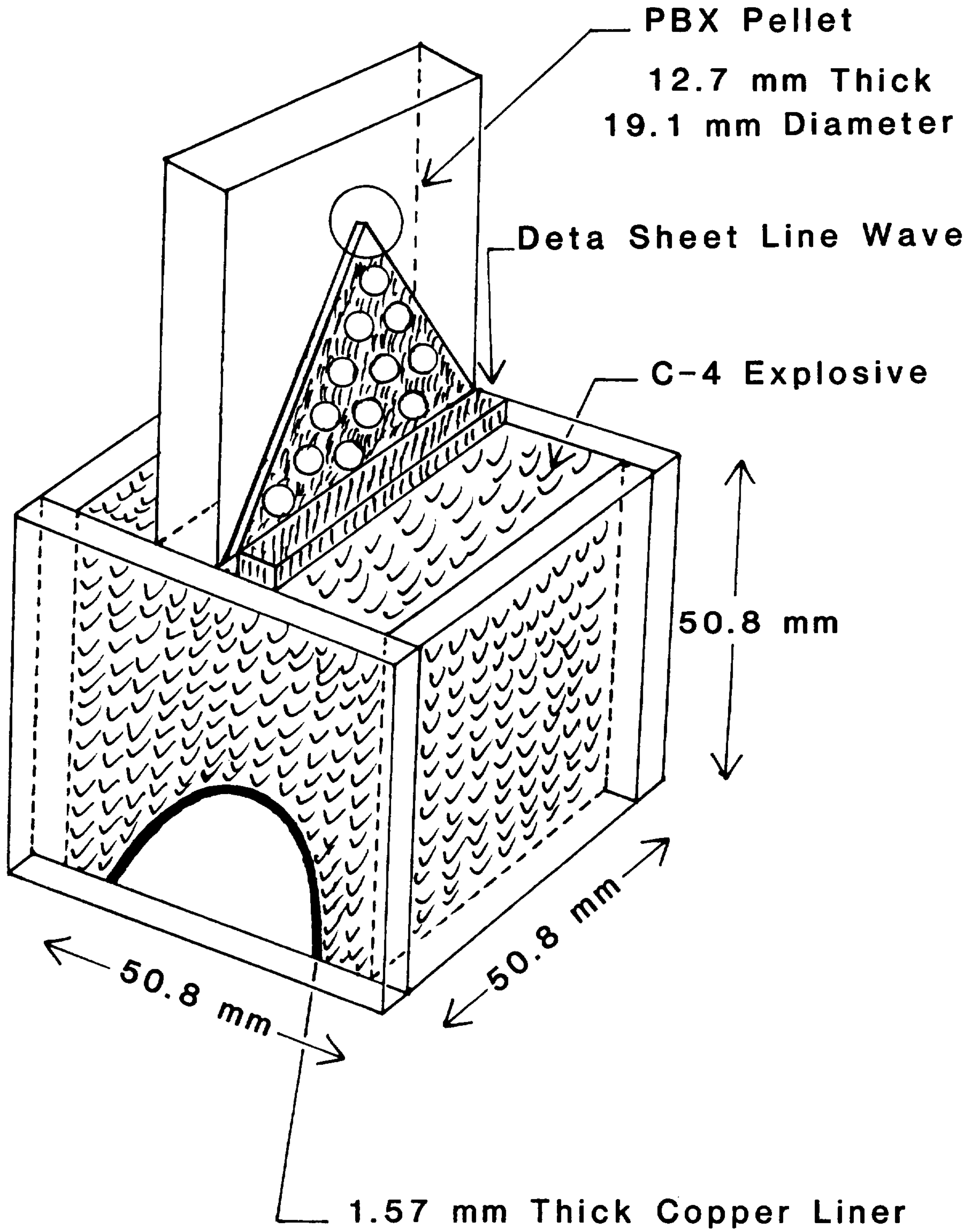

Figure 5. Linear Charge With Semi-Circular Liner

TABLE I

DESIGN NO.	COPPER LINER				EXPLOSIVE	LEADING PARTICLE VELOCITY km/s
	WIDTH OR DIAMETER mm	LENGTH mm	THICKNESS mm	SHAPE		
1	37	39	1.37	V	C-4	5.34
2	38	75	1.37	V	C-4	5.73
3	34.9	50.8	1.57	SEMI-CIRCULAR	C-4	3.03
4	34.9	50.8	1.57	SEMI-CIRCULAR	COMPB	3.16

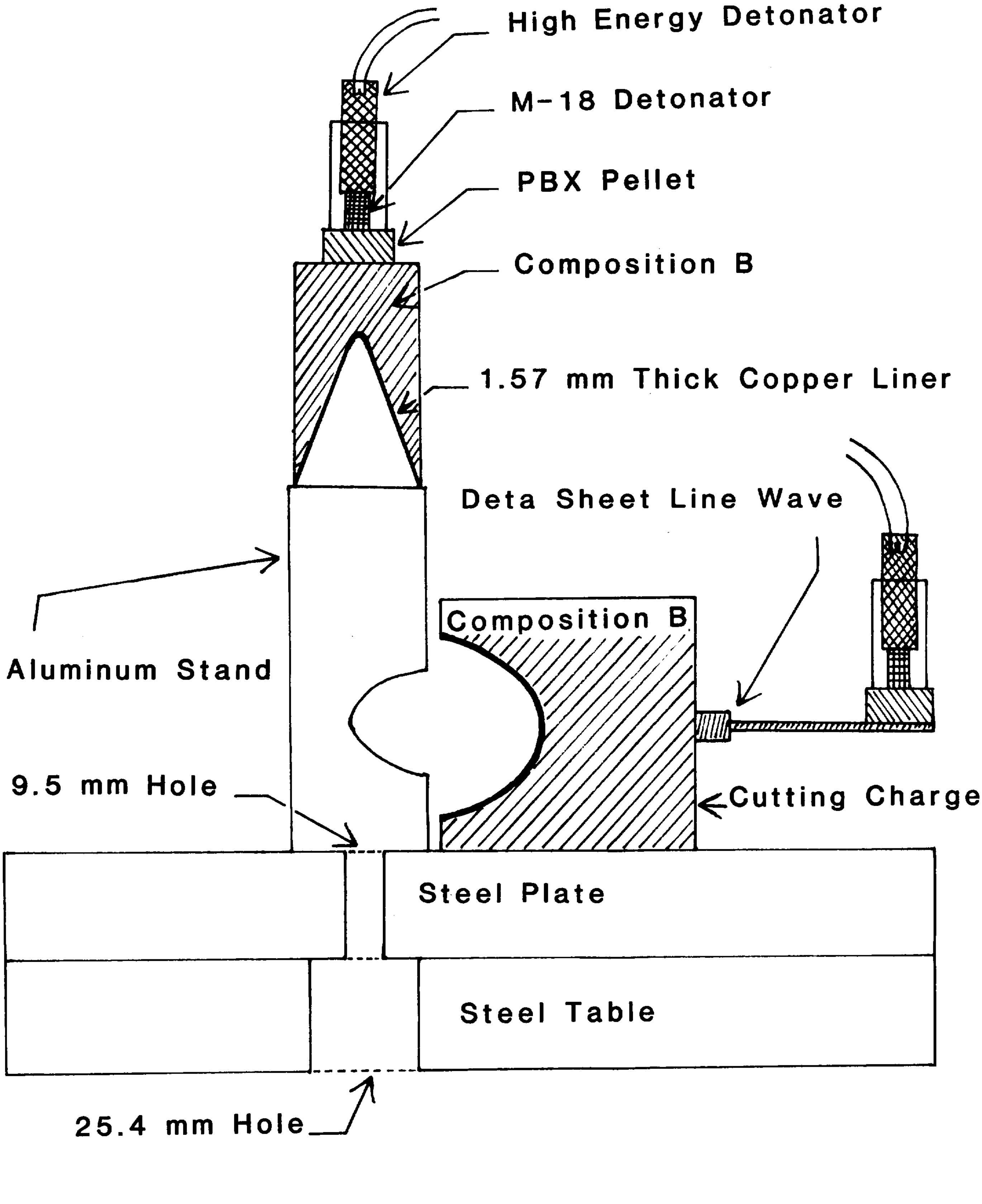

Figure 6. Jet Cutting System

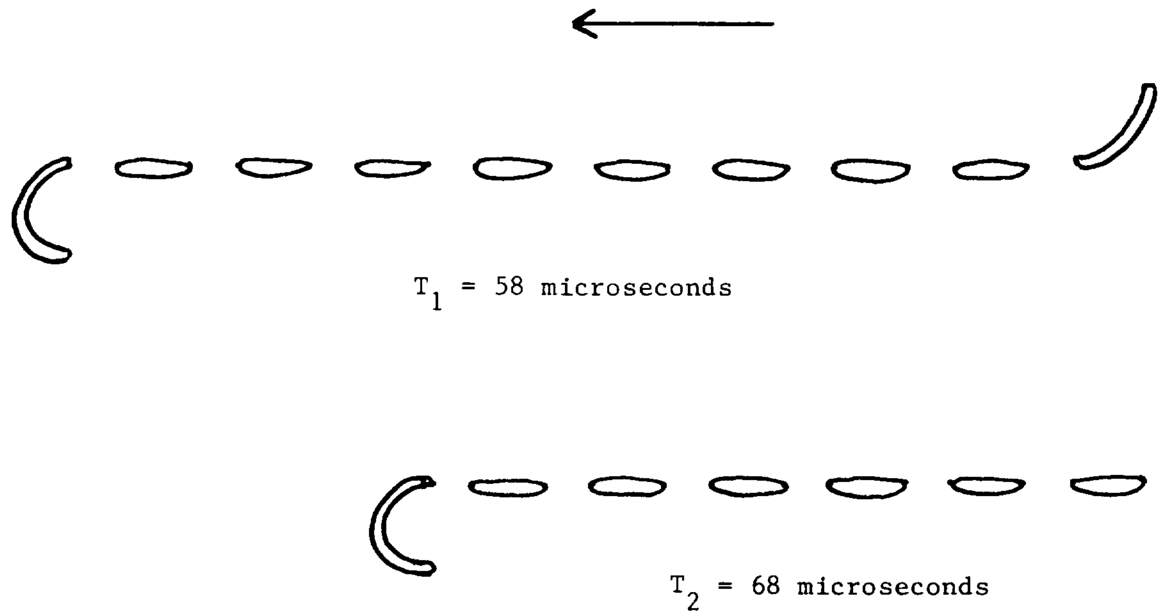

Figure 7. X-ray of Cut Jet

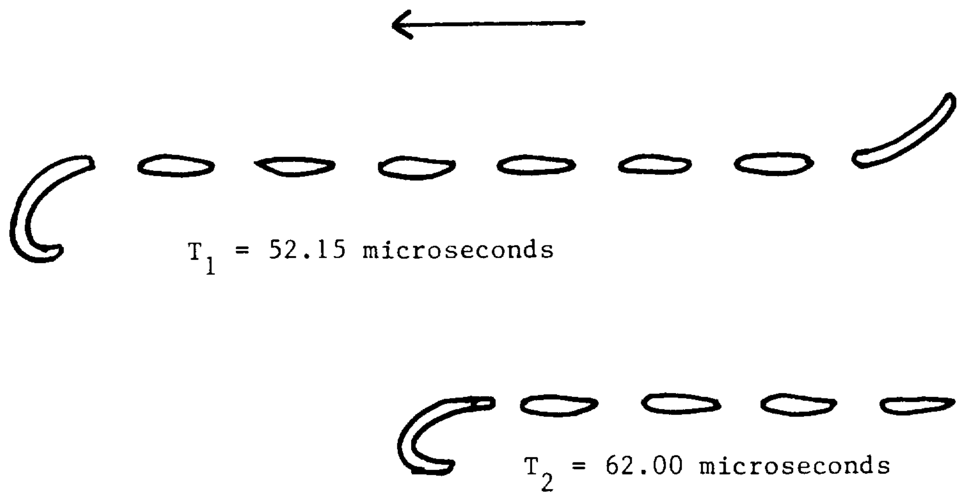

Figure 8. X-ray of Cut Jet

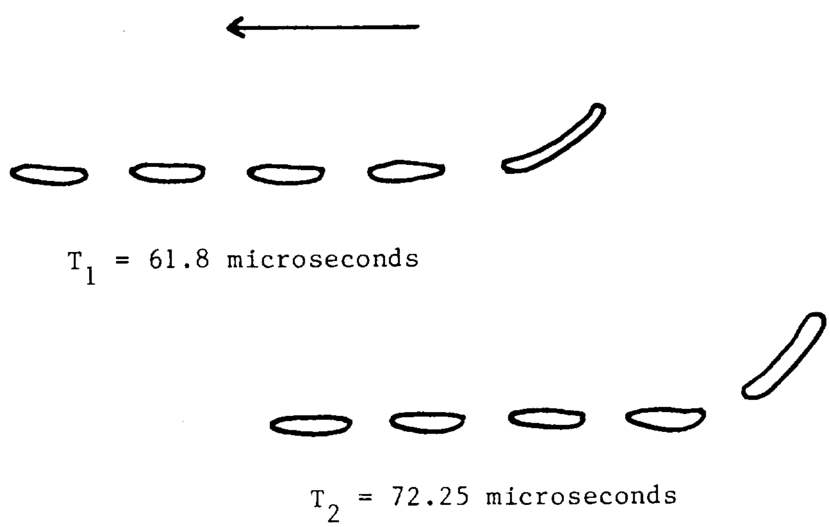

Figure 9. X-ray of Cut Jet after Penetrating Mild Steel Plate

TABLE II

PARTICLE NO.	JET PARTICLE VELOCITY KM/S	
	TEST NO.	
	20	21
1	-	7.77
2	-	7.67
3	-	7.62
4	-	7.48
5	-	7.33
6	-	7.19
7	7.05	7.09
8	6.95	6.95
9	6.87	6.80
10	6.68	6.65
11	6.59	6.41

6. CONCLUSIONS

A system has been designed to selectively cut a shaped-charge jet from a comparatively small conical liner. This will allow the study of the effect of jet velocity and length in penetration of different materials. This system was designed to be used in studying penetration in glass and ceramic targets in a small indoor blast chamber where these highly fragmenting targets are contained in steel and recovered. A similar system could be designed for larger charges and targets of different materials.

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